Design of a High-Tension, Low-Head, Hydro-Electric Power Plant

A. D. Quackenbush

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DESIGN OF A HIGH-TENSION, LOW-HEAD, HYDRO-ELECTRIC POWER PLANT

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ARTHUR D. QUACKENBUSH

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John E. Snow
Acting Director Elec. Eng. Dept.

Howard M. Raymond
Dean of Engineering

L. C. Monin
Dean of Cultural Studies.

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POWER PLANT DESIGN.

The object of this thesis is to find a logical way in which to proceed in the design of a hydro-electric plant of the low-head type. A method having been ascertained, a plant was then constructed according to this method and the article given below is a mere description of the plant in general with a limited number of calculations.

LOCATION.

The first thing was to find a suitable place of resonable amount of power and so situated that a transmission line of 150 miles or more could be used in connection with the plant. Having looked thru most of the United States Geological Survey volumes under the head of "Water-Supply and Irrigation Papers" and also some of the Army reports, it was decided to locate a plant either on the Susquehanna River in Pennsylvania or on the Chippewa River in Northwestern Wisconsin. On account of the cheapness of coal in the state of Pennsylvania it was estimated that a hydro-electric plant would not be a paying proposition and so it was decided to locate it upon the Chippewa River.

The drainage area of the Chippewa river has a length of 160 miles and a mean width of 60 miles, the total area drained being 9,573 square miles. The greater part of the entire area is heavily forested and hence there is but little chance for evaporation of surface water.

All the information with regard to the geological conditions is here quoted from "Water Supply and Irrigation Paper

No.156": "The pre-Cambrian crystalline rocks form the underlying strata in the area above Chippewa Falls, while below that point they are replaced by Cambrian sandstone. The entire area above Chippewa Falls is covered with glacial drift, so that the rock only appears in the river bed. The country is level or rolling. In the southern part the rivers have eroded deeply into the drift and rock, but in the northern portion they have not cut much below the surface.

"With only a few exceptions (the most notable one at Eau Claire) all the many and important water powers on the Chippewa River are found in the region of the pre-Cambrian crystalline rocks, but because of the deep drift the powers on the upper streams occur as bowlder rapids.

"Near the small station of Jim Falls, on the Chicago and Northwestern Railway, occurs the best opportunity for water power development on the Chippewa River. The river flows over a series of granite ledges 1 to 4 feet high, while the banks seem to be of the same rock, covered by a few feet of sandy soil."

The above gives a very general statement of the country and for lack of proper information there will arise several points which will have to be treated as alternatives. Plate 1 shows a contour map the tracing of which was made for me by the U.S. Geological Survey at Washington, D.C., and from this the map shown on Plate 10 was drawn. From the profiles shown it is seen that the greatest fall takes place at Jim Falls

where there is a descent of 35 feet in .5 mile.

HYDROGRAPHY.

In order to have a graphical representation of the quantity of water which actually flows in the river, Plates 2 and 3 were plotted from the data taken out of the "Water Supply and Irrigation Paper No.156." Since these curves cover a period of nearly three years we are safe in making an estimate of 5000 second feet discharge provided we make an allowance for some kind of storage. Plates 8 and 9 give the actual depth of the river corresponding to the flow or discharge as given on Plates 2 and 3. These curves show that the river varies from 4 to 18 feet deep and that it will be safe to figure on a minimum depth of four feet.

THE DEVELOPMENT.

There are two methods which could be used in the hydraulic development of this plant; first by placing the wheels in open penstocks or second, by building a ditch and placing the wheels in closed steel flumes. The first proposition consists of building a concrete dam 435 feet long and 48 feet high to the first spillway measured from bed rock in the river and then holding the water by two retaining walls, one 340 feet long and the other 850 feet long with a maximum height of 59 feet. The second method consists of building a dam 15 feet high and bringing the water 5000 feet thru a ditch 20 feet deep and [illegible] feet wide to a proper gate house where it is led thru steel flumes to the wheels. Instead of using a concrete retaining

wall for the first proposition, a concrete core wall or a row of piling could be used in connection with an earth retaining wall, but this is not a modern method in hydro-electric development and is subject to leaks. To sumarize: for the first proposition there will be a large dam and two long retaining walls; for the second, a smaller dam, a ditch, of the dimensions given, blasted out of rock for the greater part of the 5000 feet, and finally some sort of suitable gate house.

On account of insufficient data with regard to the above propositions, it is impossible for me to estimate which will have the lower first cost. As regards to practice, it is so varied in the hydro-electric field that no definite rules can be laid down. The only proper way to investigate such a subject would be to go to the place in question, have a thorough typographical survey made, investigate the nature of the ground rock, and soil; take into careful observation the height and general nature of the river banks and the best location for dams and the power house; and finally submit the revised data to a construction company and find out which of the two methods would be cheaper. From the electrical and mechanical standpoints the first proposition is better as the wheel regulation is far more perfect.

Assuming the cost to be about the same, we will resort to the first method on account of the better regulation. Plate 10 shows the dam to be located in the narrowest portion where the banks are steep. The profile shows that the water will

be backed up approximately 2.5 miles when the water is on the level of the first spillway. The outer heavy lines on plan show the new flood area. A portion of this area is shown to better advantage on Plate 11.

SELECTION AND DIVISION OF UNITS.

Assuming 5000 cu.ft. per second 75% efficiency for the wheels the power at the wheel shaft is given by,

$$H.P. = \frac{wqh \times .75}{550} = \frac{5000 \times 62.2 \times 40 \times .75}{550} = 17080 \text{ H.P.} = 12800 \text{ K.W.}$$

Since under conditions of design and market for the power it is not desirable to generate over 7,500 K.W. at full load and at .85 proportional discharge (.825 proportional gate opening). Making an assumption of 94% efficiency for the alternators the power required to drive them will be $\frac{7500}{.94} = 7980$ K.W. If this is to be generated at .825 proportional gate opening and assuming as low as 75% for the wheel efficiency, the water must be able to produce $\frac{7980}{.85 \times .75} = 12,500$ K.W.

Assuming 3% for excitation and 96% efficiency for the exciters we have $\frac{7500 \times .03}{.96} = 235$ K.W. which we will call 250 K.W. Assuming this power to be developed under the same conditions as above, the water must produce $\frac{250}{.85 \times .75} = 392$ K.W. Therefore there will be a total of 12,892 K.W. = 17,220 H.P. to be developed by the water at 75% wheel efficiency. The quantity in cubic feet per second for this power will be $\frac{17,220 \times 550}{62.2 \times 40} =$ 3810 which is 1190 cu.ft. per second less than assumed. This leaves a factor of $\frac{1190}{3810} = .312$, or in other words we could develop

31.5% more power than is now under consideration.

The output of the plant must be divided among several units. The division of units in a hydro plant is somewhat larger than in steam plants and, in general, depends upon the head and total amount of power being developed. Practice says that four units should be a minimum. Dividing up the power output viz. 7980 K.W. which we may call 8000 K.W. we have the following:

	4-Units	5-Units	6-Units
K.W. each	2000	1600	1333

On account of the nature of the load and in order to make the first cost of the station as small as possible it was decided to use four units of 2000 K.W. each. Since the generators are to stand 25% over load constantly and 50% over load for four hours, the turbines must be capable of producing 2680 H.P. at .825 gate or 3350 H.P. at 25% overload and full gate. In a plant of this nature it would be better to figure on a maximum of 3350 H.P. as the wheels would be working at a more efficient point.

As stated before, 250 K.W.= 375.0 H.P. is to be used for excitation. If this is divided between two units each must develop 187.5 H.P. at full load. Assuming the 187.5 H.P. to be generated at .835 proportional gate, the wheel must be capable of developing 200 H.P. thus allowing for 19.7% over-load on the exciter. The main wheel must develop 3350 H.P. and the exciters 200 H.P. each.

Plates 4,5 and 6 were plotted from data taken from "Turbine

Water-Wheel Tests and Power Tables(W.S. No. 180)" published by the Geological Survey. It will be noted that all these curves are in terms of a 10-foot head, the reason being that the greater part of the data is taken from hydraulic tests made upon the wheels at the Holyoke Testing Flume, Holyoke, Massachusetts, where the tests were made under a 10-foot head. In order to use this data two "constant" curves as shown on Plate 7 have been constructed. With these curves it is possible to find the horse power, discharge and speed at any other head when the wheels have a rated efficiency of 80%. It must be noted that the curves on Plates 4,5, and 6 are all based upon full gate opening and 80% efficiency of the wheel as would be obtained from a vertical turbine set close to the tail water. When horizontal turbines are connected in tandem, the shafts which pass through the runners become necessarily large in order to carry the power safely. The large shaft reduces the area of discharge of a given size of runner, hence the amount of water discharged being reduced, the output of the wheel will be lessened and it will not be well to figure above 75% efficiency for wheels so placed.

The generators are 25-cycle machines and therefore must run at one of the following speeds: 166.6,187.5,214,250,300,375 R.P.M. With these speeds and a wheel efficiency of 75% the following data was taken from Plates 4,5,6, and 7.

Rating of Various Wheels for a Division of 4 Units.

Name of Wheel	Diam. of Wheel.	H.P. each.	H.P. total.	No. of Wheels.	R.P.M. Wheel.	R.P.M. Req.
H	37	837.5	3350	4	215	214
C	41.2	"	"	"	221	25[illegible]
G	42.0	"	"	"	203	107.5
D	[illegible].2	"	"	"	24[illegible]	214
I	4[illegible].0	"	[illegible]	"	[illegible]1	[illegible]
E	45.0	"	"	"	1[illegible].5	1[illegible].6
A	4[illegible].0	"	"	"	170	18[illegible].6
H	45.5	1117	"	3	1[illegible]	180.6
C	47.5	"	"	"	23	214
G	48	"	"		1[illegible]	18[illegible].6
D	4[illegible].5	"	"		[illegible]7	107.5
I	51.0	"	"	"	17	214

The H.P. constant in this case is 3.75. The H.P. in terms of a 16-foot head $= \frac{3350}{3.75} = 892$ H.P. Assume next that there are four wheels in tandem; then each wheel would develop

$\frac{892}{4} = 222.5$ H.P. Now on Plate 4 draw a horizontal line thru the ordinate 222.5 and where it intersects a curve let fall a perpendicular and where this cuts the X axis will give the diameter of the wheel directly. The same method is carried out in the case of the speeds. It is not good practice to use three wheels because (1) they become comparatively large and (2) manufacturers' scales of prices are so adjusted that turbines of medium sizes, 36 to 4[illegible] inches, cost less per horse

power than do sizes, either larger or smaller: (3) When there is an odd number of wheels we have to compensate for end thrust on the odd turbine: and (4) the medium size turbines, of which the greater part are manufactured, are likely to be the most reliable and to give better service than the larger sizes.

Several of the above manufacturers were written and replies were received from three. One firm stated that the division of four units was very impractical and that they would not consider such a proposition unless the division was increased to six, while another firm stated that this would be a "very fine and up-to-date installment in every detail". Pictures and a set of data from the Holyoke Testing Flume were received from "D" and blue prints from "B","C", and "H". Firm D offered two pairs in tandem of their 42 1/2 inch wheels which will give 3,375 H.P. at 250 R.P.M. Firm C recommended two pairs in tandem of their 44 inch wheels which will give 4000 H.P. at 214 R.P.M. For the exciter, firm B offered a pair of 10-inch wheels developing 200 H.P. at 500 R.P.M.

The wheels shown in the drawings are the two pairs of 44" turbines of C manufacture. A line of these units will weigh approximately 110,000 lbs. and will cost in the neighborhood of $7,000.00. The exciters are a pair of 10" B manufacture, developing 200 H.P. at 500 R.P.M. A pair of such units cost $1500.00 and the approximate weight will be 16,000 lbs.

As stated before, the water rises to 16 or 18 feet - the rise being 12 or 14 feet. On this account it was thought advisable

to make the draft tubes 20'2" long, thus having a depth of water of 19'10" above the center line of the shaft. This is not very good practice because the regulation is better when the greater part of the head is above the wheel and only a small portion below.

For the wheel setting it will be better to quote a portion of a letter from one of the firms. "The turbines which we show in the blue prints and on which we have quoted you are equipped with balanced flutter gates hinged between the lower case ring and the crown plate, said gates are operated by means of a shifting ring mechanism which does away with all rods and levers in the water and makes it possible to operate by means of a draw rod from the outside of the flume head cover. The wheels would be arranged for installation in an open flume and the shaft at one end would be extended through a packing box and supported in the generator room by ring oiling generator type bearings beyond which would be provided a pair of face couplings for connection to generator or exciter. There would also be provided for building into the concrete wall a steel plate thimble with flanged rings to which a heavily ribbed cast iron cover plate would be bolted, said cover plate to support the housings in which racks and pinions for operating the gates are placed. The foot pounds necessary to operate the gates on the main units would be approximately 13,000 foot pounds."

The governor to be used in connection with these wheels

is type Q 7 1/2 Lombard developing 10,000 foot pounds. This was recommended by the company but it must be noted that the governor develops only 10,000 foot pounds and 15,000 are required to move the gates. If this is not large enough Type N Lombard giving 21,000 foot pounds which is of similar design may be easily substituted. The connection from the governor to the governor rod on the turbines is made by means of a sprocket chain. The sprocket wheel is attached to a pinion which workd directly upon the draw rods. The governor is fitted with a small electric motor which is controlled from the switch board. The speed regulation in connection with this motor is so delicate that the machines can be quickly synchronized. These governors hold the load within 3%. From personal observation at some of the large power houses at Niagara Falls, the recording tachometer showed the speed regulation to be within 4%.

The general dimensions of the penstocks were handed me by the turbine manufacturers as what they thought suitable for their wheels.

THE DAM.

The dam used in this installation is of the gravity type and is 465 feet long and 48 feet high to the first spillway. The elevation and section of the dam are shown on Plate 12.

Integrating the section AB of the dam we have an area of 1130 sq.ft. Assuming that the dam will be built of 1:2:4 concrete weighing 140 pounds per cu.ft., the weight of the dam proper is 158,500 pounds. The weight of the water on the

crest of the dam, assuming it to be 7 feet deep is 1 X 7 X [illegible] = 480 pounds. The total downward force is therefore 1[illegible],[illegible]0 pounds. Referring now to the graphical solution as given on Plate 12, we have the following:

Weight of BCK = $48 \times \frac{48}{2} \times 62.5$ = 72,[illegible] lbs.

" " EPK"K' = 67 X 5.1 X 62.5 = 21,3[illegible] "

" " K'CBK" = 93,300 " = pressure on dam

due to the water. Laying these forces off to scale as shown, the resultant becomes 190,000 pounds and falling within the middle third of the base proves the stability of the dam.

The drawings show that there are two spillways, one 300 feet long and the other 400 feet long. The discharge over the spillway may be calculated by the Weir formula $Q = 2/3\ c\ b\ h \sqrt{2gh}$ or $M\ b\ H^{3/2}$ where Q is the quantity in second feet. Substituting the values as scaled from the drawing,

Q = 3.35 X 300 X 8 = 8760 cu.ft. per sec. over 1st. spillway

Q' = 3.35 X 400 X [illegible] = 4110 " " " " over 2nd. spillway

12,870 " " " " total quantity of water that can flow over the dam. For draining and flushing four, four-foot sluice gates have been introduced in the dam. The quantity of water which would flow through these gates is given by $Q = 4(FV) = 4(F\sqrt{2gh})$ where F is the area of a gate and h is the head of water above it.

F = 12.56 and h = 35 Q = 4 X 12.56 X 8.02 X 5.91 = 2[illegible] cu.ft. per second.

Cubic feet per second over spillways	[illegible]
" " " " through sluice gates	2787
" " " " " main wheels	5040
" " " " " exciter "	50
" " " " " sluice gate(penstock)	1430
Total number of cubic feet	20689

Reference to Plates 2 and 3 will show that there are only a few intervals of the year when the flow of the river exceeds these figures and this excess quantity will be held back for storage.

It will be noted above, that each penstock has been provided with a three-foot sluice gate for the purpose of draining the penstock or keeping it dry due to a leaky gate. The time required to empty such a penstock through the sluice gate is found by the formula $\left[{}_0^n t = -\frac{F'}{\mu F\sqrt{2gh}} \cdot \int_{z_0}^{0} z^{\frac{1}{2}}\, dz\right.$ where z_0 is the depth of the water, F' area of vessel parallel to surface of the water, F area of sluice, and μ the co-efficient of efflux. Integrating, $t = \frac{2F'z_0^{\frac{1}{2}}}{\mu F\sqrt{2g}} = \frac{2F'z_0}{\mu F\sqrt{2g z_0}}$ (Church. Mech. of Eng. P 738). Substituting the values,

$$t = \frac{2 \times 23 \times 44 \times 24}{.64 \times 7.03 \times 8.02 \times 4.89} = 274 \text{ sec.} = 4.56 \text{ min.}$$

THE GATES.

The head gates are shown in both the plan and elevation. These gates are built in two portions, each sliding up and down in proper guides built in the concrete walls. In order to

strengthen the penstock, I beams imbedded in concrete are used in the form of beam and on these are located the gate hoists.

In order to calculate the thickness of the wood for these gates, each piece may be considered as a beam supported at two ends and since it is uniformly loaded with the water (pressure) we may consider this pressure concentrated at the center. Assume a beam to be 10 feet long and one foot high and the pressure exerted by a 24 foot head would be 10 X 1 X 24 X 62.5 = 15,000 pounds. Equating moments, $\frac{R'I}{e} = \frac{W \times l}{8}$. Assuming $R' = 144,000$ for timber,

$$\frac{(144,000)bd^2}{6} = \frac{15,000 \times 10}{8}$$

$$d^2 = \frac{15,000 \times 10 \times 6}{8 \times 144,000} = .781 \therefore d = .8825' = 10.6 \text{ inches.}$$

This is for white pine. By using white oak and a safety factor of three,

$$d^2 = \frac{15,000 \times 10 \times 6}{8 \times 144 \times 2400} = .085 \therefore d = .292 \text{ ft.} = 3.5 \text{ inches.}$$

In order to have good even lumber four inch stock white oak was used. In one of these gates for each penstock is a 2-foot filler gate so that the penstock may be filled first and thus the pressure on both sides being equal the larger head gates may be opened much more easily. If each gate is 10 feet wide and 16 feet long, the total pressure due to a 24 foot head will be 10 X 16 X 16 X 62.5 = 160,000 lbs. If .35 is the co-efficient of friction of wood on metal, the force required to raise the gates due to water pressure will be .35 X 160,000 = 56,000 = 28 tons. To this must be added the weight of the gate itself, so in all

there would be a total force of 30 to 35 tons required to lift the gates when there is water on one side and only the weight of the gate itself (neglecting the buoyancy effect) when the pressure is equalized by water on both sides. The method of hoisting these gates is shown in both the plan and elevation and consists merely of a standard gate hoist operated by either hand or motor.

THE POWER HOUSE.

The power house is built entirely of 1:2:4 reinforced concrete. The building proper is 122' wide and 141' long. On one side are the four main turbine penstocks each 44' long, 23' wide and separated by a 6-foot wall. In the center is the exciter compartment. This is divided into two smaller compartments each 8 1/2 feet wide and 17 feet long. The east wall of the power house is 3 feet thick and serves as a portion of the dam. Since each penstock is 23 feet wide and assuming the water to be 26 feet deep, the total pressure exerted upon the wall in each penstock will be 23 X 26 X 13 X 62.5 = 486,000 lbs. The foundation of the power house consists of five concrete arches each 137 feet long, four having 22-foot span and the exciter one having an 18-foot span. The arches are of an elliptical design the rise being 4 1/2', crown 3', and abutments 8' thick. The water passes through the penstocks into the wheels and hence down the draft tubes in these arches and then out into the tail race. In order to reduce churning of the water within the arches and to improve the action of

the wheels, the depth of the water is kept 15 feet below the end of the draft tubes.

The generators being of such dimensions, it became necessary to make a cut 13'-3" long, 5'-5" long and 3' deep into the crown of the arch. In order to strengthen the arch at this point I beams were placed in the concrete below the generator frame and the entire crown was bored under and well reinforced by rods as shown in the elevation.

Along the west wall of the generator room is the switchboard gallery 26 feet long and 11 feet wide. This is built into the wall on one side and supported by iron columns on the other. The floor of the balcony is 13 feet from the floor and is of such a height that the operator can easily observe the operation of all the machines. The balcony is reached by an iron stairway from either end and a third iron stairway leads from the balcony to the high tension bus room and to the other rooms on the second floor of the station. The generator room measures 31 feet by 135 feet and is spanned by a 20 ton traveling crane.

THE ELECTRICAL EQUIPMENT.

A. Generators.

The generators are of the water-wheel type, have a rating of 2000 K.W. at full load, will stand 25% overload continuously and 50% overload for two hours. They are three-phase 25 cycle machines running at 214 R.P.M. and generate at 12,000 volts. The total weight of a unit is 155,000 lbs., the

heaviest part weighing 40,000 lbs. and the fly wheel effect at one foot radius was calculated to be 700,400 lbs. These machines require 185 amperes excitation at 125 volts when running 50% overload and at .80 power factor. The units are coupled directly to the water wheel shafts by means of a flanged coupling which may be put together or taken apart in less than five minutes. In order to keep the voltage up as the speed of the turbine decreases due to either the head becoming low or tail water backing up, it was decided to run the alternators on a low portion of the magnetization curve at full load. As the speed and hence voltage fall, the strength of the field may then be increased, thereby holding the voltage to its normal value. Of course as the speed decreases, the frequency will decrease but since the power is being supplied to rotaries for railway work this will not be of such a consequence as the maximum decrease will not be over 6%.

There are three sets of exciters each being independent of belt drive. In some power houses, the exciters are belted to the alternator shafts, but for the most part this is poor practice, for as the speed of the alternator falls, the voltage of the exciter will also fall when in reality it should rise to maintain the voltage constant. If the units are independent of belt drive the voltage may be varied at will. As stated previously there are two motor driven exciters each rated at 125 K.W. at 500 R.P.M. and generate at 125 volts. The number of K.W. taken by the alternators will be $\dfrac{4 \times 185 \times 125}{1000} =$

97.6 so it is seen that each exciter will be of sufficient capacity for the entire plant including station lighting. In addition to these water driven exciters, there is a 150 K.W. motor generator set. The motor has 6 poles and the frequency being 25 cycles, the synchronous speed will be 500 R.P.M. This is a three-phase, variable-speed induction motor requiring 440 volts for operation. The generator develops about 145 K.W. at 125 volts. The object of this motor generator set is (1) for general excitation in case any trouble occurs on the water driven exciters; and (2) for charging the storage battery system. The object of using a variable-speed induction motor is (1) the induction type of motor is the cheapest; and (2) it will be desirable to raise the speed so as to obtain a comparatively high voltage which must be used in charging storage batteries where no booster has been installed. All three of the exciters are cumulatively compound, the equalizer switches being located at the exciter instead of the switchboard. The object of locating these switches here is that the heavy copper leads that must be carried to the switchboard gallery increase the first cost and for good division of load, the equalizer leads should be as short as possible.

D. The Transformers.

The main transformers are 850 K.W., oil insulated water-cooled, transform from 12000 to 62000 volts, and are of the single-phase type. There are just as many sets of transformers as there are alternators, the object being to have a

distinct unit from the generator to the high-tension [illegible]ars. [illegible] The alternators are rated at 2000 K.V.A. or [illegible] 2500 K. V.A. and will stand 2500 K.V.A. continuously, the size of a transformer to carry this load will be $\frac{2500}{3}$ = 83[illegible] K.V.A. The transformers selected are 350 K.V.A. and are so built that they will stand 50% overload for two hours. If any one of the transformers would be damaged, this one could be taken out and the spare transformer put in its place in less than two hours. Meanwhile, the four alternators may be used in connection with the remaining three sets of transformers thus leaving the service uninterrupted. The transformers are connected delta on the primary and Y on the secondary. Since the voltage across any phase on the high tension side is 62,000 volts, the pressure across a secondary winding will be $\frac{62,000}{\sqrt{3}}$ = 3[illegible] volts.

The ratio of transformation will be $\frac{3[illegible]}{12[illegible]}$ = [illegible].132.

The three leads drop from the low-tension transformer oil switch through brass pipe down to the top of the transformer case. On the case is a second set of brass pipe which carries the wires forming the delta connection. The [illegible] shows how the connections are made. One very particular feature about these transformers is that there is only one secondary lead brought out through the case. Since the high-tension side is star connected the other lead is grounded upon the case on the inside of the transformer. The transformer cases are very

well connected through all the water and pressure piping and consequently give a good electrical connection of low resistance. The advantage of so connecting a transformer is (1) the better insulation obtained and (2) there is no star connection necessary outside and hence there are less wires carrying high potential.

The water for cooling purposes comes through duplicate systems of piping from the turbine penstocks and since the height of water is above the transformer, the water will flow or circulate by gravity. The warm water is carried away thru piping which discharges in the arched tail races directly beneath. Each transformer is fitted with a four-inch pressure piping which leads to the tail race also. The pipe is connected to the top of the transformer case and carries a relief or pressure valve which opens one way only. If a short circuit should occur within one of the cases, the intense pressure of the gases thus generated would open the valve and allow them to escape rather than blow the entire transformer to pieces. The cases are all tested to withstand 150 lbs. per square inch explosive pressure. Such a transformer alone weighs 26,000 lbs.

Each set of transformers is located in a pocket 25' x 28', the intervening walls being 12 inches thick. The floor of these pockets has a slope of 2 1/2 inches toward a drain which is located along the west wall of the station. Any water due to leaks in the pipes carrying cooling water will be properly

drained off. The transformers are located four feet from all walls and the nearest proximity of any two cases is three feet. There is sufficient room to work around any part of the transformer and to remove one and replace it by the spare. Reference to the plan and elevation will show that the pockets are 18" higher than the floor of the entire plant. A small car which runs on a standard gauge track and has its top on a level with the floor of the transformer pockets is used in transporting a transformer from one place to another. Any transformer may be placed upon this car by means of crowbars and then it may be carried to another pocket or may be run along the track till it comes to a small turn-table. Here the car is turned at right angles and may be pushed out into the generator room where a crane may pick it up and place it on a railroad car which has been brought into the plant. The transformer room is 35' wide, 104 1/2' long, and 17 feet high in the pockets. Besides the main transformers, there are three 30 K.V.A., oil-insulated, self-cooled, single-phase units, transforming from 12,000 to 440 volts. These transformers are located in the high-tension bus room and are cut off the 12,000 volt bus by means of an oil switch operated from the switchboard. These transformers are connected delta on both the primary and secondary sides. Their object is to furnish a source of supply for operating the induction motor generator set and the traveling crane. These units are 54" high, 43" in diameter and weigh 3875 pounds each.

3. The Circuit of the Plant.

Assume the ultimate capacity of the alternators working at .6 power factor and substituting in the equation

$$P = \sqrt{3}\, E I \cos\theta , \qquad 2500 \times 1000 = \sqrt{3} \times 12,000 \times .6 \times I \;\therefore\; I = \frac{2500 \times 1000}{\sqrt{3} \times 12,000 \times .6} = 200 \text{ amp.}$$

Allowing 1000 circular mils per ampere we must use a 200,000 circular mil cable to carry the above current. The connection is made at the alternator in the proper pot head to this 200,000 circular mil 12000 volts, three-phase cable. The cable is carried through a split vitrified duct under the floor and then taking a bend of large radius goes up the wall in a chase and finally terminates in a pot head where the leads connect directly to the low tension generator switch. The chases in the walls are covered with a thin layer of concrete so that the cable can be taken out at any time. Split duct was used in preference to solid because of the ease in the handling of the cable.

In the lower compartment of this oil switch, taps are taken off and lead to two potential transformers located in the barriers of the low-tension bus compartments. These transformers are connected in delta.

From the generator switch the leads pass through the floor, being supported on the ceiling of the transformer room and then run to a point directly beneath the low-tension bus bars. Here the leads again pass through the floor up into the barriers, through current transformers and disconnecting switch and hence

to the low tension bus. From the low-tension bus, leads run to disconnecting switches located in the barriers and hence to the low tension transformer switch where leads drop directly through the floor to the transformers.

The two sets of switches mentioned are of the G.E. H 3 type having a rating of 200 amperes at 13,000 volts. These switches are operated by small motors which are controlled from the switchboard. The disconnecting switches, current and potential transformers are also all of G.E. standard design.

The low-tension bus and barriers are built up of reinforced concrete, the scheme being plainly shown in the elevation. The reason for employing concrete for this construction is because of the cheapness and the admirable way in which it withstands heat or fire. The entire bus compartment structure is 2'7" wide, 6'4" high and 84'6" long. The compartments in which the busses are located are 1[illegible]" wide and 8" high. In these compartments the insulators support a horizontal bus of copper which carries three knife switches thus cutting the bus up into four parts. We will assume the same current density in this bus as was used in the cable there will be 4 X 200,000 = 800,000 circular mils which we will take as 1,000,000 circular mils = 785,400 sq. mils = .7854 sq. in. Assuming the copper to be 2" wide, it will require [illegible] strips [illegible]/8" thick clamped together in the proper way.

The connection to the transformers was described before. The high-tension transformer leads run directly from the trans-

formers toward the West wall and at a point 2'6" from this wall turn and pass upward through the floor and a concrete tube 2 feet in diameter and 5 feet high. The wires are supported by passing through the centers of two pieces of plate glass mounted within these tubes. These concrete tubes serve the double purpose of insulation and keeping a person from accidentally coming in contact with a wire. Directly above the tube is a disconnecting switch of standard G.E. practice. From the switches the leads pass directly into the high-tension type G Westinghouse switch. It is well to note that all the leads enter the Westinghouse switch at the top and was chosen as the most suitable type for the bus system employed. Another feature on the high-tension switch is that each leg of a phase is in a compartment of its own surrounded by boiler plate, while in the G.E. switch, each leg is in a brick compartment and small wooden canisters are used to hold the oil. Solenoids are used to both close and open these switches instead of motors. From these switches the wires are tied directly to the high-tension bus bars which are built of 1/4 inch copper tubing well wrapped with oiled linen. This high-tension bus is fastened to standard high-tension insulators provided with a special part in which two bolts are fastened. With these bolts the insulators are fastened to a 10" channel beam which is laid in the concrete walls of the plants. The insulators are so designed that a bus is at no time nearer to ground than two feet and the distance between phases has been arranged to

be six feet.

Reference to Plate 15 will show that the high-tension bus is sectionalized between the two sets of switches, thus enabling two alternators to feed to each line or all four alternators to feed to either one of the lines--these lines are in duplicate. The nearest proximity of any two phases about the high-tension work is five feet; so there is little danger unless something extraordinary takes place.

At the north end of the station the high tension bus bars drop down to current transformers as shown in section CD, Plate 15. From here they pass through the high-tension line switch and hence into the lightning arrester barriers, through a choke coil, disconnecting switch and then to line. The current transformer is of a standard Westinghouse design and is fitted with two secondaries, thus only one transformer being needed for the operation of the overload relays and instruments.

Sections CD and EF give an idea of the lightning arrester barriers. The line goes through a plate of glass three feet in diameter mounted in the wall as shown. Going toward the station, the line passes through a sectionalizing switch of standard design, then through a choke coil consisting of 19 1/2 turns of copper wire. Just below this coil the main line goes to the line switch and a tap is taken off and runs below the floor level where it connects to a disconnecting switch mounted on the ceiling of a compartment below. The other side of this switch connects directly to a potential transformer

through fused circuit breakers. These transformers are connected open delta and are located in a compartment by themselves.

The lightning arresters are provided with disconnecting switches so that they may be entirely cut from the line. These arresters are of type G.E. form V, shunt resistance, multiplex, star connected with neutral grounded. The outer portions of the lightning arresters are 16'5/16" long, the middle leg is 18'9 5/16" long and the disconnecting switches are 38" long so that the total length of the middle or largest leg is 21'11 5/16".

D. Switchboard and Wiring.

The switchboard is built of 1 1/2" blue Vermont marble, is 7'6" high and 14'8" long. The panels are mounted on pipe set an inch or more from the marble so that all control and instrument wires may be run directly against the panels.

The panels are equipped with the following instruments: (a)Generator(4 in number). 3 ammeters, (1)direct current field ammeter, (1)polyphase indicating wattmeter, (1)power factor indicator, (1)voltmeter: (1)voltmeter switch for obtaining the voltage on any phase; (1)synchronizing receptacle; oil switch control with red and green indicating lamps: (1)200 ampere carbon break field switch with discharge terminals and resistance; (1)25 ampere D.P.D.T. switch for operating the electrically controlled rheostats;(1)15 ampere D.P.D.T. switch for

governor control; (3)overload and timelimit relays(mounted on rear of panels). B-Line Panels(2 in number). (3)ammeters; (1) graphic recording wattmeter; (1)control switch. On the rear of each of these panels is a polyphase integrating wattmeter and the over load and time limit relays.

C-Exciter panels(3 in number). Each panel has a 1200 ampere D.P.S.T. exciter switch,a shunt field switch,an ammeter and a voltmeter switch for obtaining the bus bar voltage or voltage of an incoming machine. The panel to the extreme left has in addition,a 1200 ampere tie switch, a switch for charging the storage batteries,a switch for throwing the batteries on the operating bus and a storage battery ammeter having the zero in the center of the scale. On the lower slabs,of the other two panels are the 440-volt bus bars,which connect directly with the 60 K.W. transformers. On the center panel is a 3 P.S.T. 200 ampere,440V switch for operating the crane and in the center of the upper slab is a 100 ampere switch for station lighting. On the lower slab of the right hand panel is a 500 ampere T.P.S.T.,440 V switch for operating the motor generator set. An A.C. ammeter has been provided so that the operator may observe the motor loading. A lighting switch has been provided on this panel being similar to the switch on the center of the middle exciter panel.

D- Swinging bracket contains the synchroscope and the exciter voltmeter.

wiring diagram.

This is shown in Plate 10 and since all connections are shown, requires very little explanation. In order that the service may remain uninterrupted, the exciters are tied directly to the exciter bus without circuit breaker or fuse. The shunt fields are excited from the bus and consequently the machine will always come up to voltage with the proper polarity in the shortest possible time. The rheostats for the entire plant are of the woodpecker type and are located in a well ventilated duct directly beneath the switchboard gallery. By opening the bus tie switch the storage batteries are charged from the motor generator set. This switch was installed so that the motor generator could be cut from the exciter bus when charging, for the voltage then required might be 10 to 20% higher than that of the bus. By closing the bus control switch, battery and tie switches, the batteries can be made to float on the exciter system. The voltmeter switch is of special design and may indicate the bus bar, storage battery or the incoming machine voltage.

The instruments on the generator panels are all of standard G.E. design. The overload relays were placed on the rear of the board so as to be isolated. The clothing of an operator is liable to brush against the tripping device and thus open an oil switch when under load thereby causing an undesirable delay in the service.

With the three ammeters, power factor indicator and volt-

meter on each phase and the polyphase indicating wattmeter [illegible] can check the output of each machine. The ammeters were placed upon the feeders so that the operator could tell, at a glance, the load and to see if the phases were balanced. The graphic recording wattmeter were installed so that a continous load curve of the plant might always be on hand and the integrating watmeters were used so that the power for a definite period may be obtained.

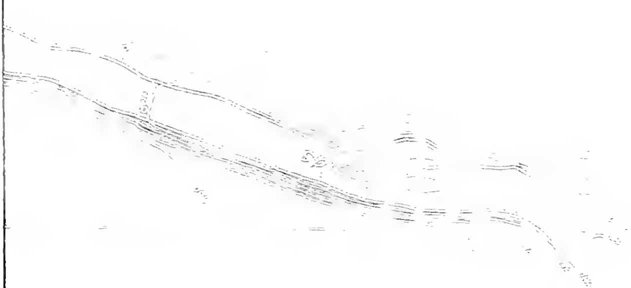
A glance at Plate 16 will show that each alternator may be run as a separate unit up to the high tension bus. A duplicate bus was considered but for this size of load and the nature of the service it was concluded that the system shown would be practically as good. The low-tension concrete bus work is so built that a duplicate set of low tension bus bars could very easily be installed. 60,000 volt potential transformers are shown in the various views of the installation but the first cost could be materially decreased if 12,000 volt transformers of the proper ratio were used instead and placed at the point just before the lines enter the transformers. All the instruments and switches with the exception of the exciter switches are fused on the rear of the board by N.E. Code enclosed fuses.

Miscellaneous.

A boiler room is shown on the plan. A [illegible] H.P. boiler has been installed for general heating purposes and for thawing the turbines out in case of a freeze. The heating pipes are

placed along the walls of the various rooms and a header is run to each penstock where a flexible connection can be made to the turbines and any part subjected to live steam. A coal bin 12.5'X7' is filled through a coaling door from the exterior of the plant and holds enough coal for a four weeks' run. Two doors have been provided in the entrance to the boiler room so that all dirt and smoke may be kept from the rest of the plant.

Above the store room on the second floor are a lavatory, locker room, store room and storage battery room. The storage battery room was thus located so as to have the best possible advantages of ventilation and isolation and also to have the advantage of good day light.



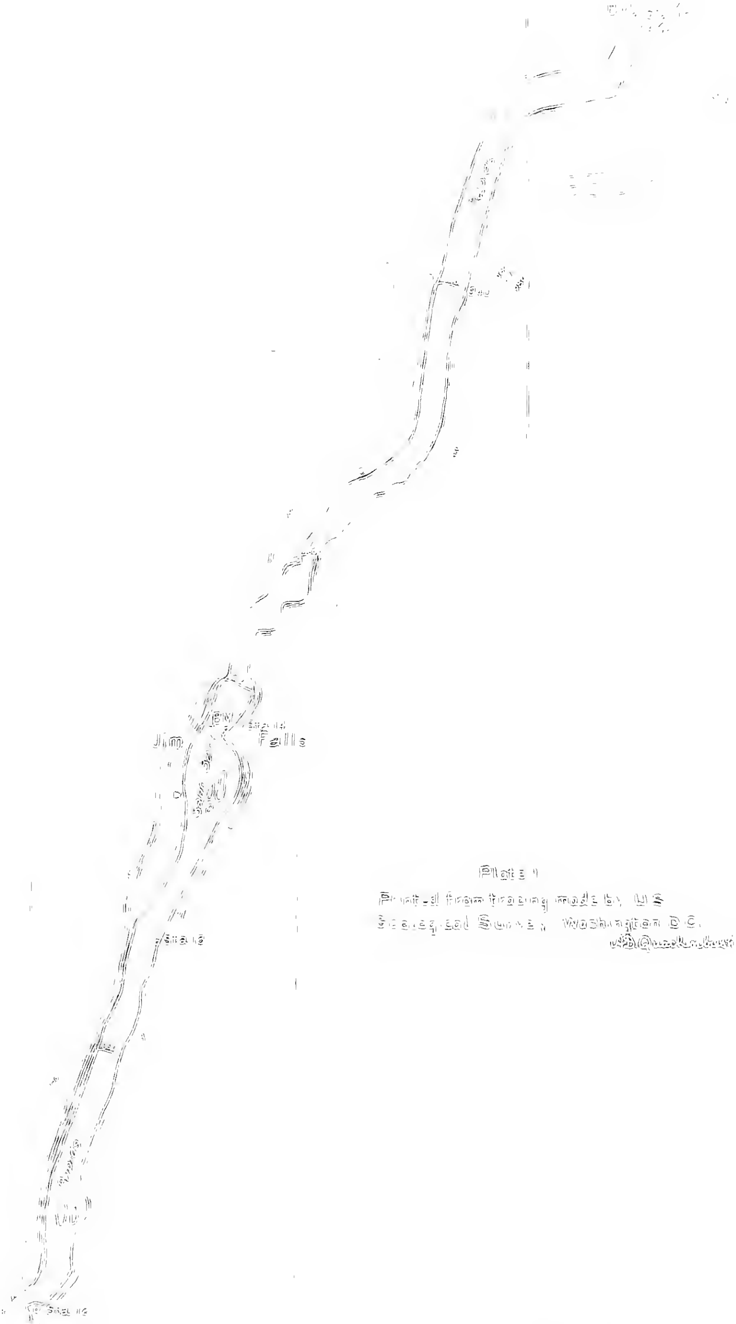
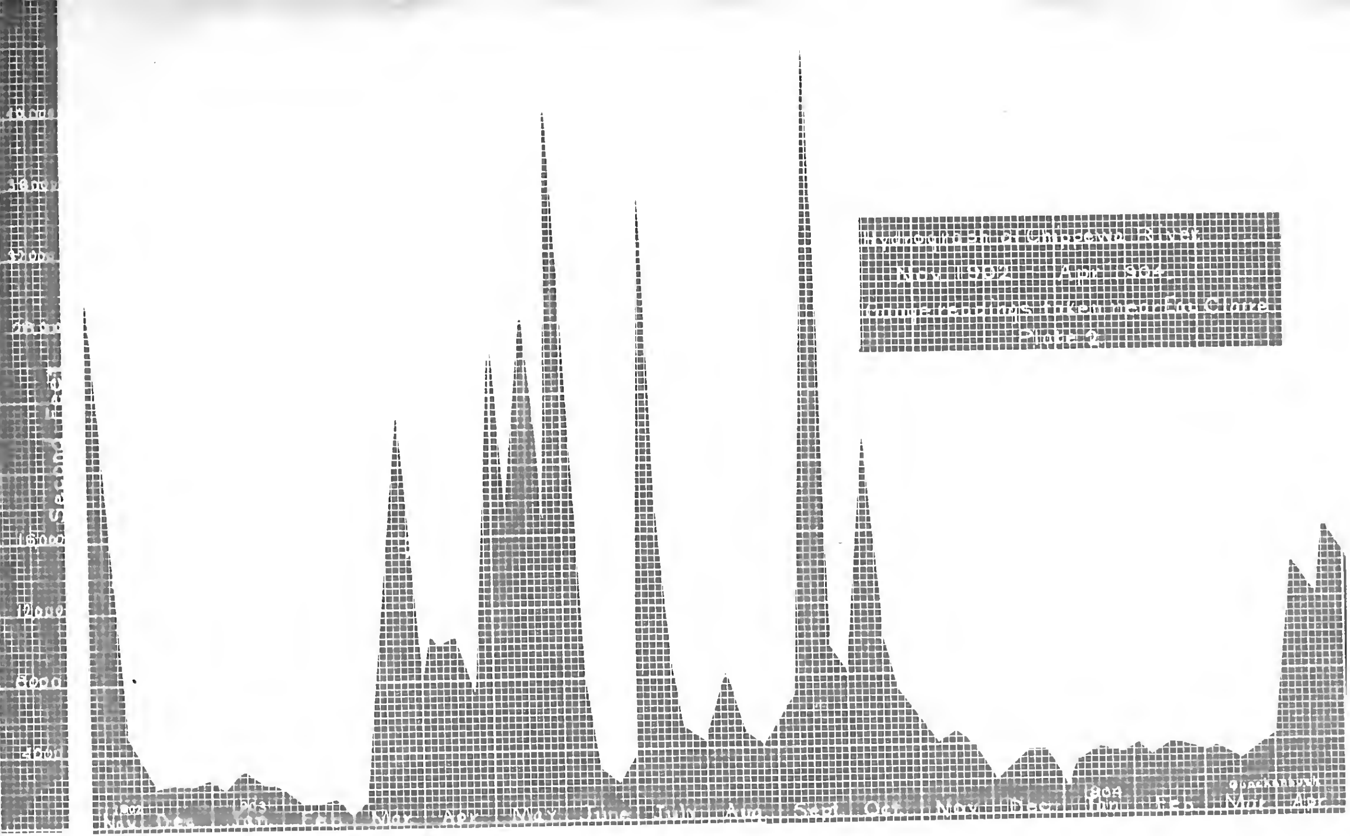


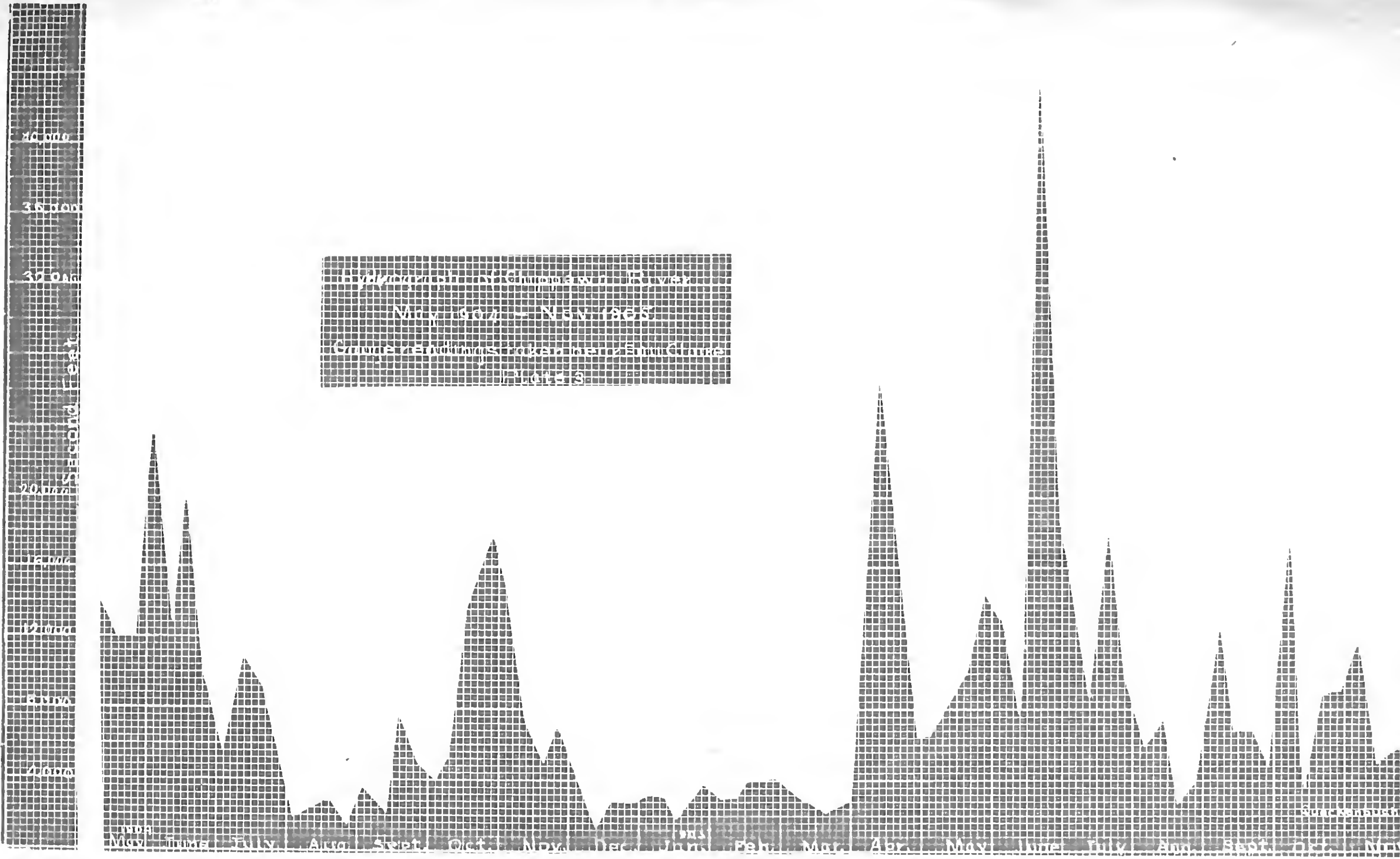
Plate 9

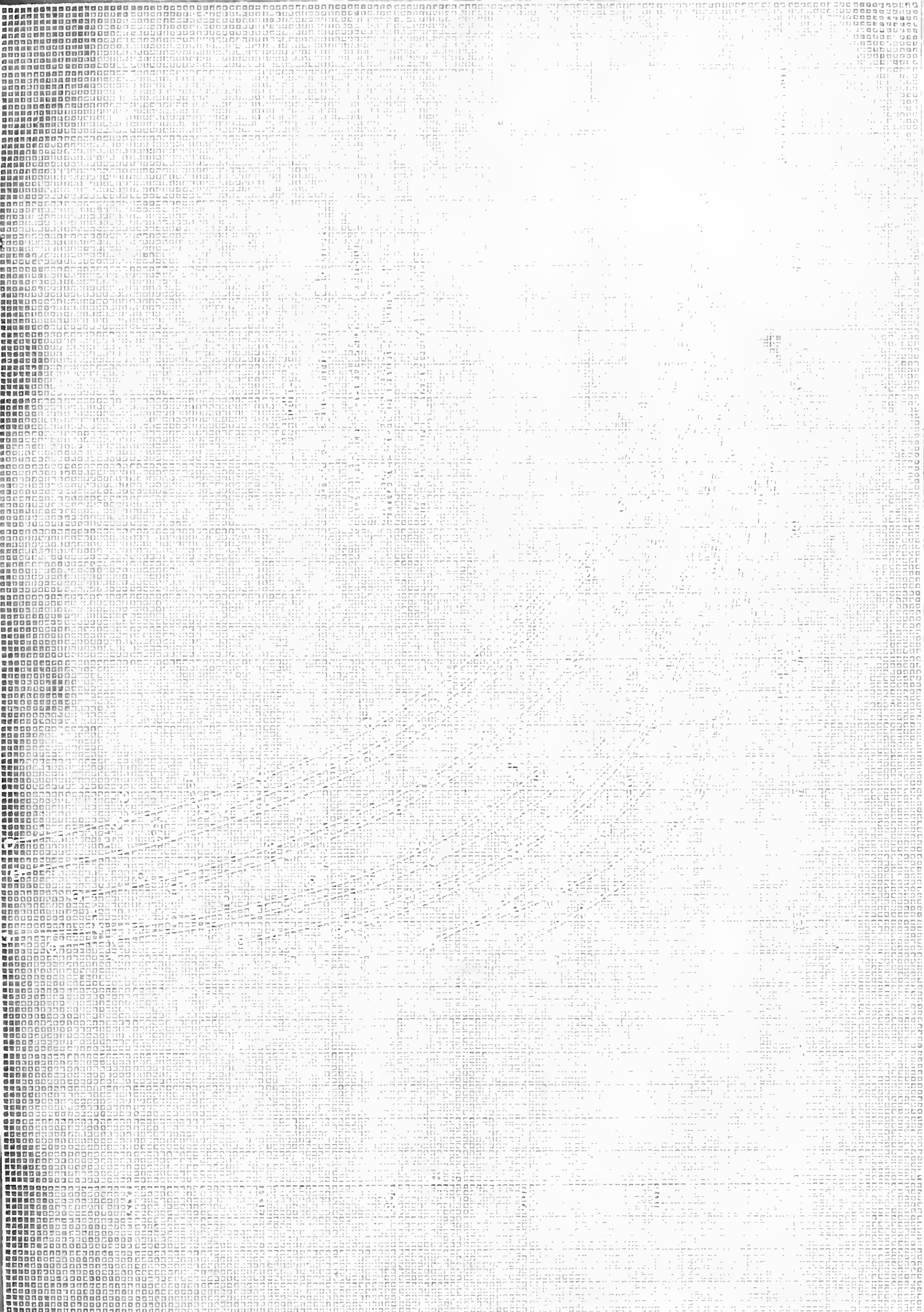
Printed from tracing made by U.S. Geological Survey, Washington D.C.

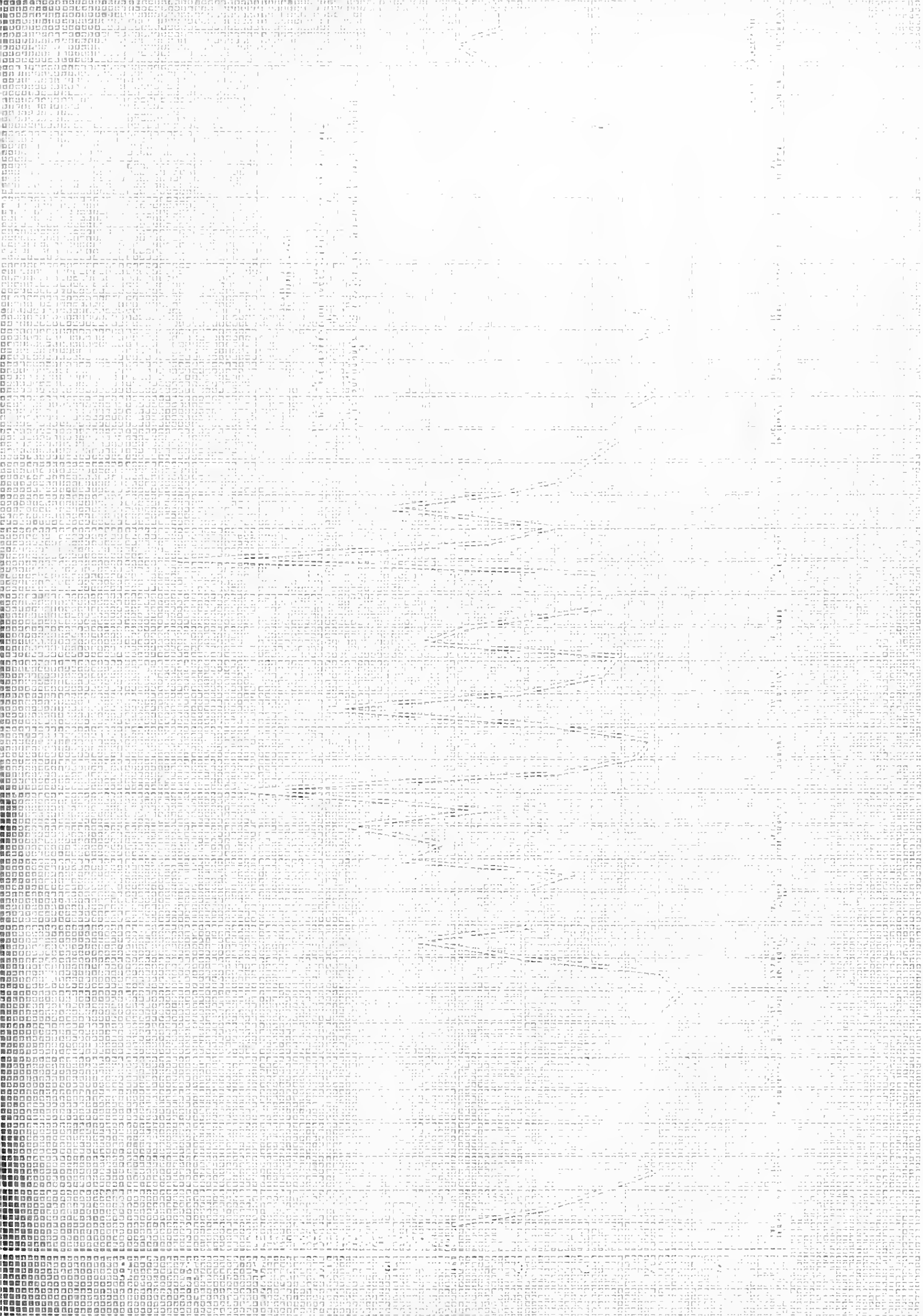
W.B. Quackenbush, '07

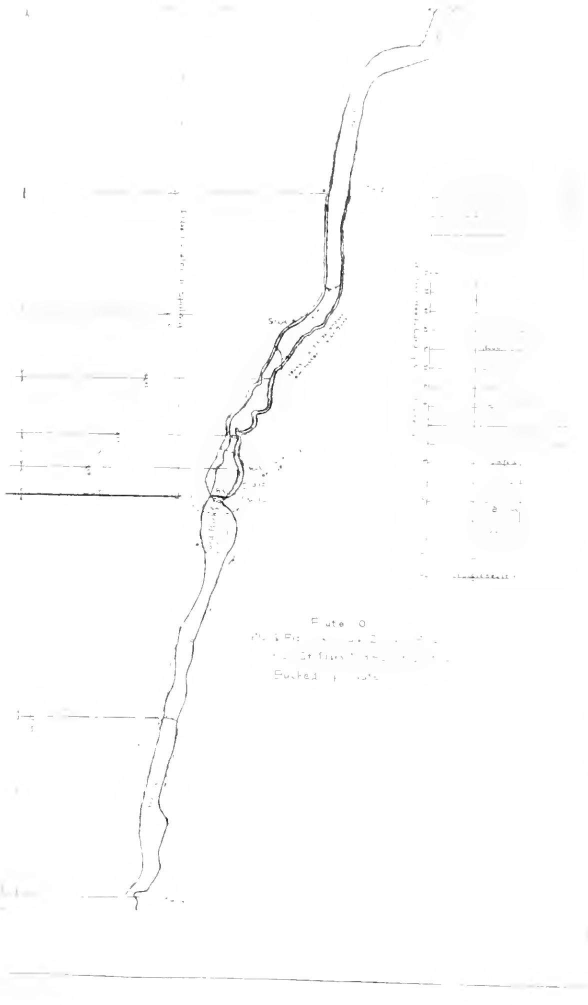


Hydrograph of Chippewa River
Nov. 1902 — Apr. 1904
Gauge readings taken near Eau Claire
Plate 2


Hydrograph of Chippewa River
May 1904 – Nov 1905
Gauge readings taken near Eau Claire
Plate 3
Second Feet
20,000
16,000
12,000
8,000
4,000
1904
May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov
1905







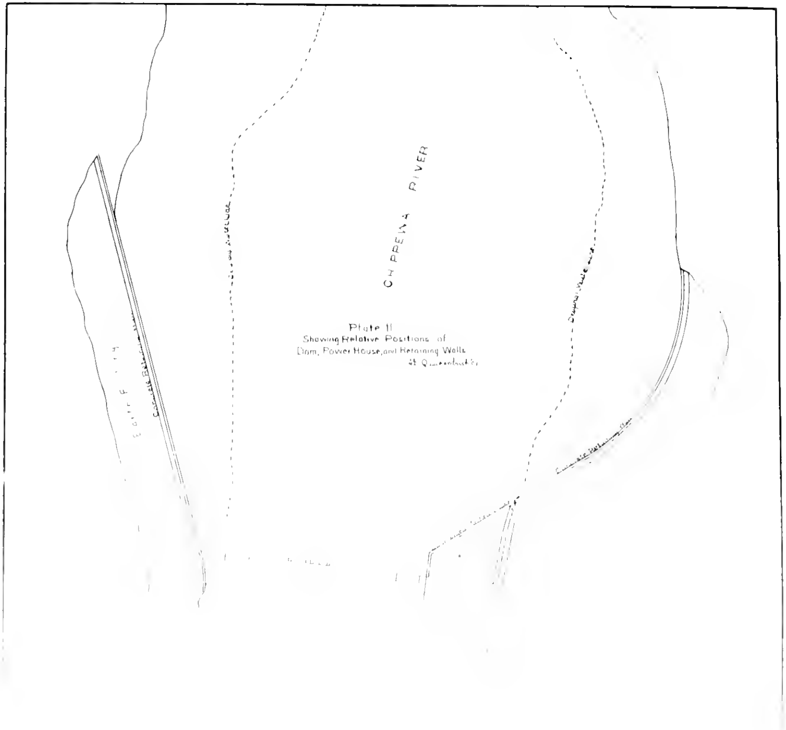
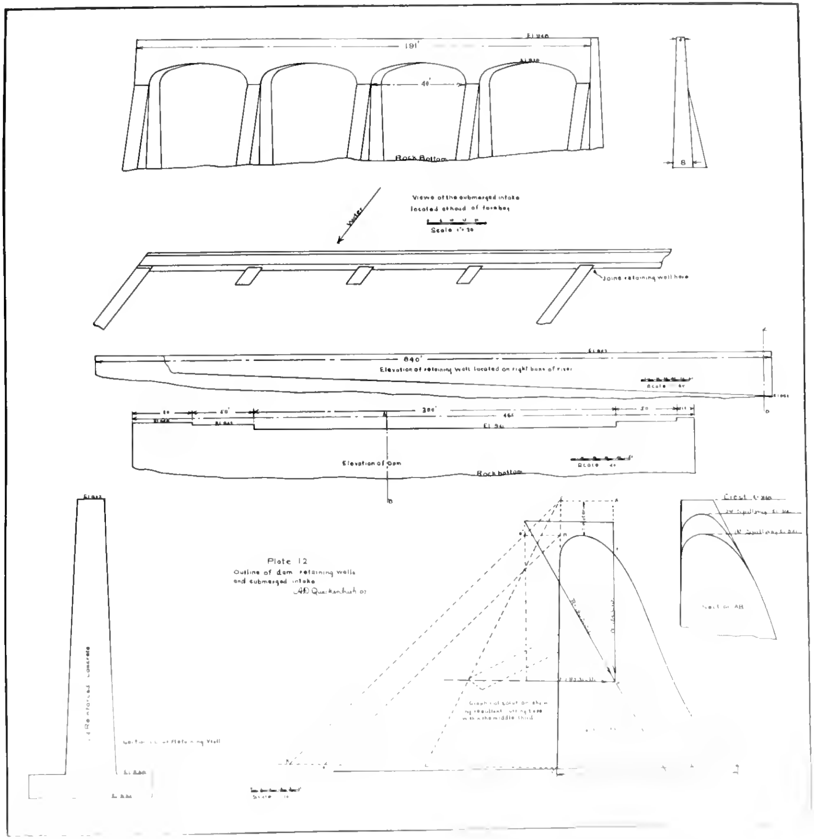
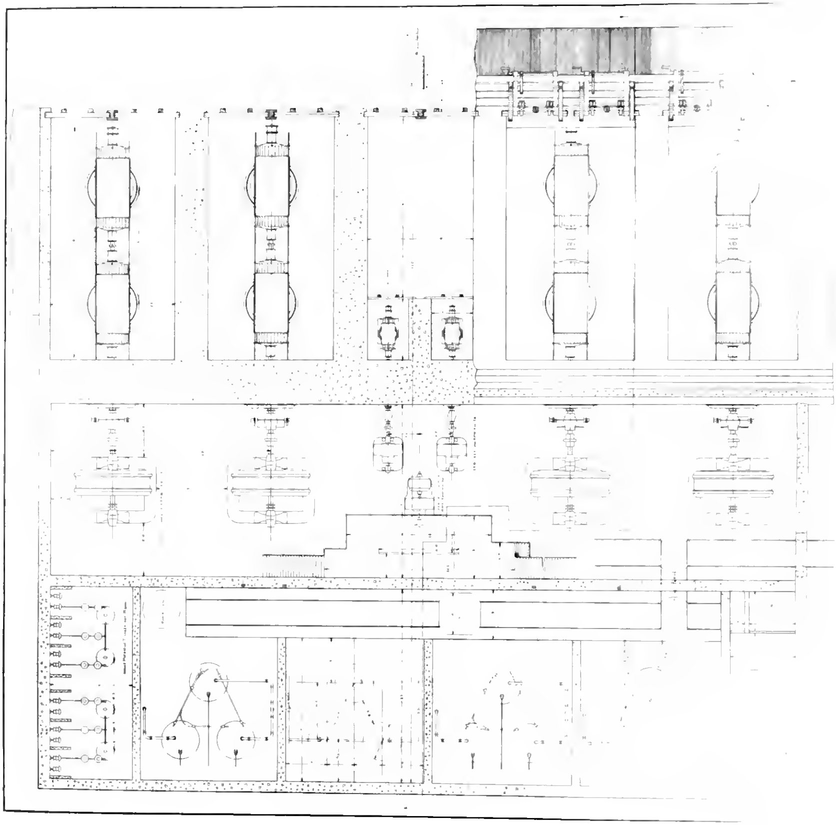
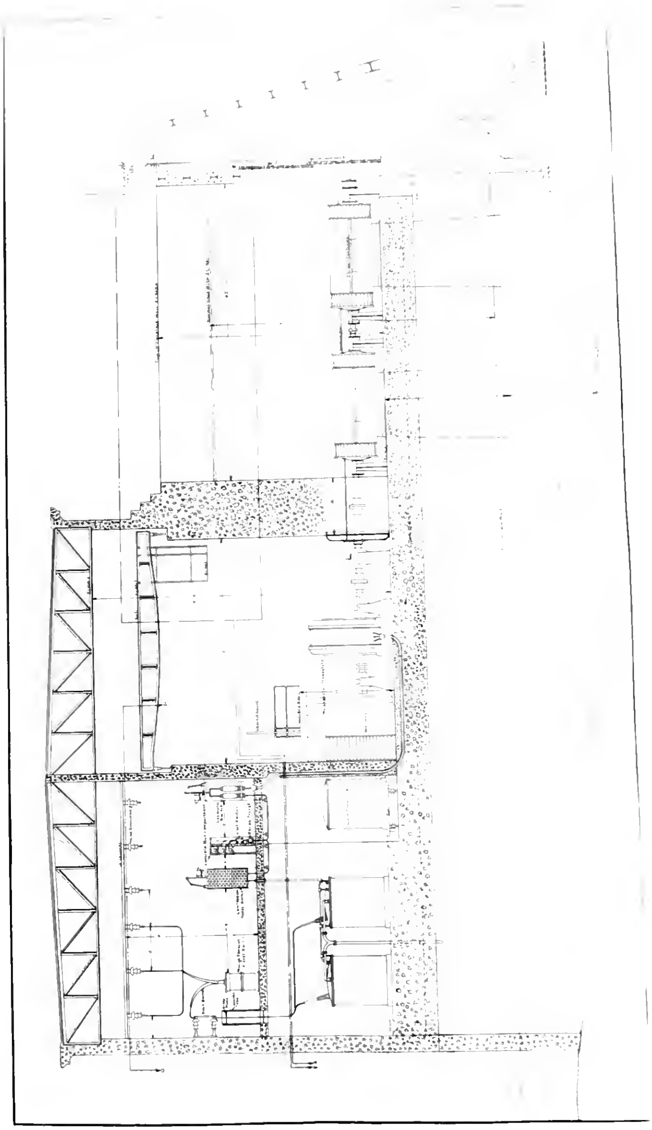


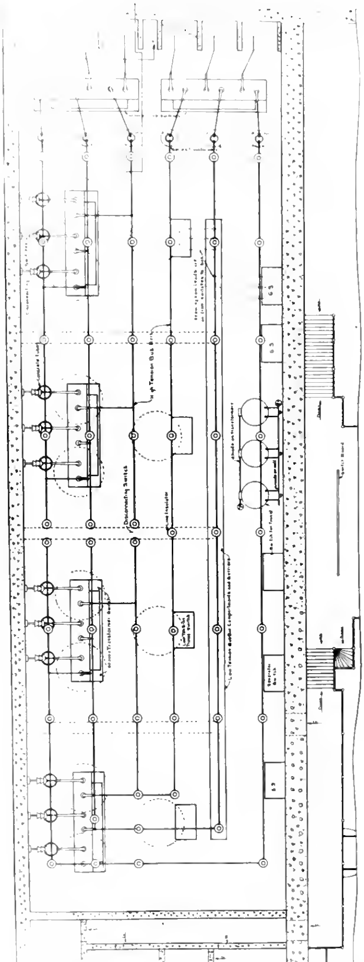
Plate II
Showing Relative Positions of
Dam, Power House, and Retaining Walls
at [illegible]

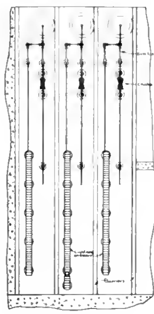


191'
40'
Rock Bottom
Views of the submerged intake
located ahead of forebay
Scale 1"=20
Water
Joins retaining wall here
840'
Elevation of retaining wall located on right bank of river
300'
Elevation of Dam
Rock bottom
Plate 12
Outline of dam retaining walls
and submerged intake
A.D. Quackenbush 07
Reinforced Concrete
Sect. on AB
Crest
8

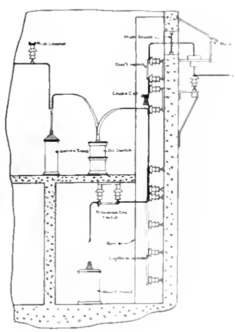








Section E F showing ... lightning arrester barriers



Section C D showing ...

Plate 15